

**APOLLINARIS PATERA. AN ASSESSMENT BASED ON THE 2001 LANDING SITE EVALUATION CRITERIA.** M. H. Bulmer<sup>1</sup> and T. Gregg<sup>2</sup>, <sup>1</sup>Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, Washington, D.C. 20560. <sup>2</sup> Dept. Geology and Geophysics, Woods Hole Oceanographic Institution, MA 02543.

Site (Geographic Name and Co-ordinates):

Apollinaris (8.5°S, 186°W) is located on the highland/lowland boundary.

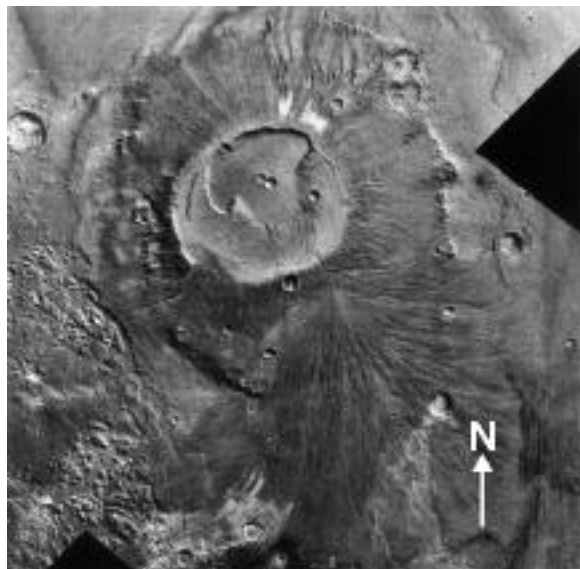


Figure 1. Image of Apollinaris Patera. Width of the image is ~ 235 km. From Robinson et al. 1993.

Exploration of a planetary surface via a rover is similar to investigation of the deep sea floor using remotely operated vehicles (ROVs) or deep submergence vehicles (DSVs). In both instances, scientists are challenged by having to choose their target sites using large-scale, low-resolution data sets (e.g., bathymetric maps of the seafloor, or orbital images of another planet); and, once on site, are able to maneuver within only a few hundreds to thousands of meters of the landing site. In the search for biologic communities at Earth's mid-ocean ridges (MORs), for example, it is important to note that the

vast majority of the MOR system is completely barren of life: no microbes live in the thousands to hundreds of thousands of meters that separate the life-sustaining hydrothermal vent fields. In other words, on Earth's ocean floor, biologic communities exist only within small oases associated with recent (<100 kyr) volcanic or magmatic activity, and are not found elsewhere. Furthermore, some of the bacterial species abundant at these hydrothermal vents are in fact among the most primitive life forms on Earth, and appear to be among the earliest life to have evolved on Earth.

Life at Earth's MORs thus raises two points, pertinent to the search for life on Mars and selection of a landing site for the 2001 mission: 1) primitive life-forms on Earth most likely developed at sites containing both abundant water, and magmatic heat; and 2) these sites on Earth cover small areas (typically  $\ll 1 \text{ km}^2$ ) and are separated by great distances (generally  $\gg 1 \text{ km}$ ). Given Athena's limited range (~3 km), it is crucial that the 2001 landing site be carefully selected to maximize the discovery of past or present life on Mars, as a misplacement of just a few kilometers could completely bypass an ancient Martian oasis. For example, life at Earth's MOR hydrothermal fields was not discovered until 1977, after almost two decades of DSV exploration. Therefore, we propose that the search for life on Mars can be optimized by locating sites where there is evidence for both magmatic heat sources and abundant water.

Apollinaris Patera is a volcano located near the martian crustal dichotomy, and appears to have been active from the Lower Hesperian through the Amazonian [Tanaka 1986; Robinson et al., 1993]. Like Tyrrhena and Hadriaca Paterae, Apollinaris apparently had an early history of explosive volcanism with a transition to more effusive volcanism [Greeley and Crown, 1990; Gregg et al., 1998]. Gulick [1998] has proposed three landing sites around Apollinaris Patera for the Mars Surveyor 2001 mission. Here, we present reasons why Apollinaris Patera would be ideal for the 2001 landing site. Until MOC and MOLA data are available for the area we refrain from detailing an actual landing site by latitude and longitude.

### **Evaluation Criteria:**

- Ability to successfully sample ancient highlands materials likely to preserve paleoclimatic information, and, if they exist, pre-biotic compounds and evidence of life.

Apollinaris Patera and the surrounding terrain contain environments favorable for the production and preservation of pre-biotic compounds and/or fossils. First, it is possible that the chaotic terrain on the west flank of the volcano originated from flooding from Ma'adim Vallis [Scott and Chapman 1995; Cabrol et al., 1996]; flood deposits may therefore contain biotic compounds which could have developed in standing water at Gusev crater [Goldspiel and Squyers 1991; Grin and Carbol 1997]. Second, the chaotic terrain may have formed through the melting of large volumes of ground ice [Sharp 1973; Carr and Schaber 1977; Robinson et al., 1993] as a result of volcanic activity at Apollinaris Patera. In this case, magmatic heat from Apollinaris could have warmed pools of standing water,

and provided energy for hydrothermal circulation systems over much of the volcano's history [Gulick, 1993, 1998; Gulick et al., 1998]. This combination of heat and water is an incredibly fertile environment for life and pre-biotic compounds on Earth--both on land (e.g., Yellowstone) and at mid-ocean ridges. Furthermore, the circulation of warm (and probably slightly acidic) water through volcanic deposits commonly causes the deposition of silica polymorphs, which would encase and beautifully preserve any evidence for life. Materials sampled around the western, and southern flanks of Apollinaris will provide information on paleoclimatic conditions plus volatile abundances and input into the determination of the origin of the chaotic terrain. Rating: 8

- Evidence of rapid burial or other mechanisms likely to concentrate and preserve evidence.

Volcanic deposits--especially volcanic ash--are among the richest sources of fossils on Earth today. Ash falling on land, on the ocean, and on lakes and ponds, rapidly buries and readily preserves any evidence for life (including prebiotic compounds). Apollinaris displays evidence for explosive eruptions in the Hesperian [Robinson et al., 1993] and therefore provides an unequalled opportunity for the preservation and collection of rocks containing information on the early climatic history of Mars, as well as evidence for life. In addition, if the chaotic terrain adjacent to Apollinaris Patera was formed through flooding of Ma'adim Vallis (Scott and Chapman 1995; Cabrol et al., 1996), these flood deposits possibly including some Noachian rocks (Scott and Chapman 1995), by definition, would have rapidly buried--and preserved--pre-biotic compounds and/or fossils,

as well as possible rocks containing information on the paleoclimate. Rating: 10

- Relative paucity of surficial aeolian cover (higher thermal inertia and lower albedo, without being hazardous).

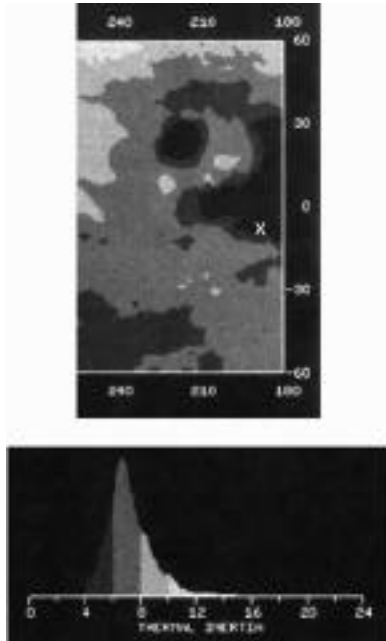


Figure 1. Effective thermal inertia for the Apollinaris Patera region. Values are expressed in units of  $10^{-3} \text{ cal cm}^{-2} \text{ s}^{-1/2} \text{ K}^{-1}$ . Modified from Christensen 1986.

IRTM data over Apollinaris is listed in Table 1. Figure 1 shows that Apollinaris is located in an area of low-inertia. The average IRTM values for Apollinaris range from 3.8-4.5, and for the surrounding plains from 3.0-3.5. Pass A569-7 and B551-11 provide information on the nature of the chaotic terrain on the western flank of the volcano [Robinson et al., 1993]. The data indicate the presence of dust greater than 2 cm thick [Jokosky 1979]. The resolution of available imagery is currently insufficient to determine the aeolian cover in the proposed site, but aeolian processes have shaped the terrain and possible wind streaks

occur on the northern margin of the volcano. Pass A648-2 and A492-8 provide information over the northern and eastern flanks and surrounding terrain, also indicating the presence of a dust layer >2 cm thick. Rating: 8

- Presence of areally extensive targets within approximately 3km.

Landing on the NW margin of Apollinaris ( $7.5^{\circ}\text{S}$ ,  $187.2^{\circ}\text{W}$ ) appears in the Viking data (Figure 3, site A) to be in line with engineering requirements for the relatively smooth landing site, and within 3 km of this site flows from Apollinaris can be sampled along with materials in the knobby plains which are of proposed Lower Amazonian age [Greeley and Guest 1987]. Landing on the NE margin of the volcano ( $6.8^{\circ}\text{S}$ ,  $184.5^{\circ}\text{W}$ ) in a part of the Amazonian channel emanating from the Medusae Fossae formation would provide the rover with the opportunity to sample the areally extensive plains to the east (Figure 3, site B), which are interpreted to be made up of lava flows interbedded with aeolian or possible pyroclastic materials considered to be mid-Amazonian in age [Greeley and Guest 1987]. The rover could also sample a range of excavated volcanic materials incorporated within the crater ejecta on the west flank of Apollinaris.

Landing within the chaotic terrain near to the flanks of Apollinaris ( $8.6^{\circ}\text{S}$ ,  $187.4^{\circ}\text{W}$ ) is likely to hazardous given the current lander constraints (Figure 4, site C), but will allow sampling of these areally extensive materials plus volcanic products which form the base of the volcano. To the west of this site the rover could sample a range of excavated volcanic materials incorporated within the crater ejecta (Figure 1). Rating: 8

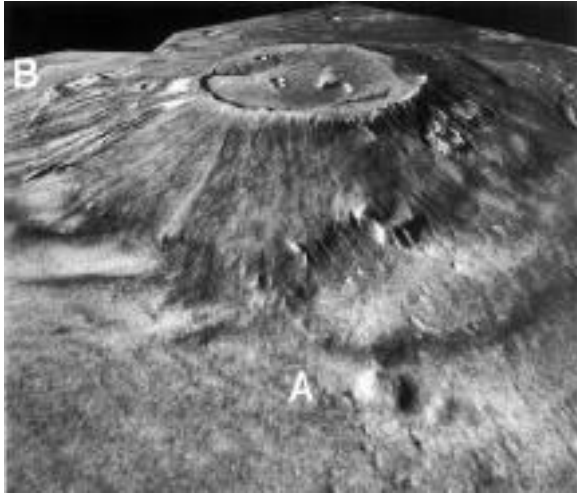


Figure 3. Perspective view of Apollinaris as seen from the NW looking SE, vertical exaggeration 2x. Proposed landing sites are shown by letters A and B. Modified from Robinson et al. 1993.

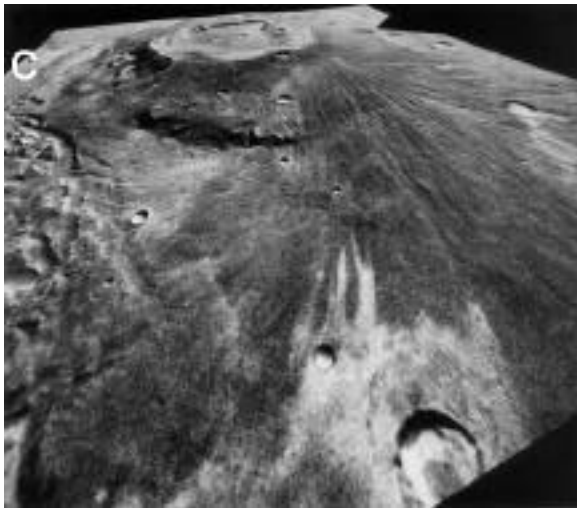


Figure 4. Perspective view of Apollinaris viewed from the SW of the volcano. Vertical exaggeration 2x. Proposed landing site on the west flank in the chaotic terrain is shown by letter C. Modified from Robinson et al. 1993.

Current data do not have sufficient resolution to address Athena's precise requirements. Figure 5 shows that the abundance of surface rocks around Apollinaris expressed as the fraction of the surface covered by material of inertia 30 is ~5% [Christensen 1986]. This figure is close to the 6.9% rock abundance for the VL1 site. For such a site there is a 99% probability of not landing on any rocks greater than 35 cm in height (equal to lander clearance) which meets with the 99% Project goal for Landing success with the caveat of the low-inertia material masking possible underlying rocks. The safest landing site and apparently best in terms of rover trafficability is to the north at site A. On the eastern flanks of Apollinaris near site B there are two craters ~25 km in diameter which pose a potential hazard (Figure 1 and 3). The proposed site C is relatively smooth in Viking data but the target area which is 15 by 15 km requires landing precision beyond the current project requirement of a miss-distance less than 50 km. The crater values for the surrounding plains at  $N(2) = 100$  where  $N(2)$  is equal to the number of craters 2 km in diameter /  $10^6 \text{ km}^2$  [Greeley and Guest 1987]. From digital elevation models derived using geometrically corrected images 603a42 (612 m/pixel) and 639a92 (717 m/pixel), slopes on the flanks of the volcano are determined to be  $\sim 6^\circ$  [Robinson et al., 1993; Thornhill et al., 1993]. Rating: 7-8

- Landing safety and rover trafficability as evidenced by rock abundance, thermal inertia, and image data.

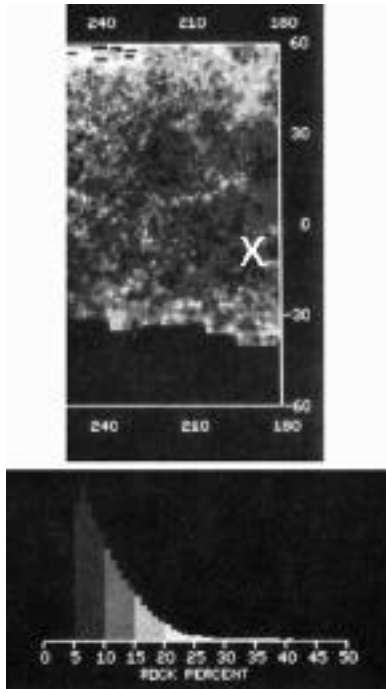


Figure 5. Abundance of surface rocks in the Apollinaris region expressed as the fraction of the surface covered by material of inertia 30. Values were determined by modeling VO1 T<sub>7</sub>-T<sub>20</sub> data. Modified from Christensen 1986.

- Ability to test hypotheses within the observational capabilities of Athena, and to meet the Athena Science objectives of determining the geologic and climatic history of a site where conditions may have been favorable to the preservation of possible evidence of biotic or pre-biotic processes.

The observational capabilities and science objectives of Athena (i.e., determining the geologic and climatic history of a site) can all be met at Apollinaris Patera. Based on comparisons of the eruption rate at Apollinaris with that at the Hawaiian hot spot, the former has been active over an estimated 10<sup>7</sup> years [Robinson et al., 1993] and the available evidence strongly favours the chaotic terrain being formed during the active lifetime of the volcano. Thus, two of the principal conditions

necessary for biotic processes--water and time--existed. The five main science objectives of Athena can all be met at Apollinaris: obtaining stereo images, indentifying the elemental and mineral compositions of rocks and soils, determining fine-scale textural properties of materials, and finding samples which preserve evidence of paleoclimate and possible microbial activity. Furthermore, sampling at Apollinaris Patera provides us with the opportunity to collect primary volcanic materials which can reveal vital information about mantle and magmatic processes--including volatile evolution--through time. Rating: 10

- On a "target of opportunity" basis, collect a variety of materials.

If the chaotic terrain on the western margin of Apollinaris Patera is the product of a flood event, then Athena could sample a wide variety of highland materials of Hesperian and possible Noachian age at an Apollinaris Patera landing site. To the NW of Apollinaris Patera, possible mass-wasted materials would be sampled, as well as the sequence of volcanic deposits which comprise the apron of Apollinaris Patera. To the NE of Apollinaris Patera, materials that might be sampled include those of volcanic origin excavated by the impact event plus those from the impactor and the material which makes up the surrounding plains. Rating: 9

- On a "target of opportunity" basis, collect samples that will permit calibration of the crater size frequency distribution.

Given the areally extensive nature of the plains surrounding Apollinaris which are accessible from sites A and B, and the crater density on the units it should be possible to

collect samples that will permit calibration of the crater size frequency distribution. Rating:  
8

Tanaka 1986, J. Geophys. Res. 91.  
Thornhill et al., 1993, J. Geophys Res. 98.

Table 1: Available data:

Thermal Inertia-

Spacecraft	IRTM track
Viking Orb	A569-7
Viking Orb	A648-2
Viking Orb	A492-8
Viking Orb	B551-11

Images -

Spacecraft	Orbit	Emiss Ang	Incid Ang	Res m/pixel
Mariner 9	177A13	1	38	1000
Viking Orb	088A50	44	38	192
Viking Orb	506A75	9	38	585
Viking Orb	603A42	29	69	614
Viking Orb	609A47	26	27	835
Viking Orb	635A57	23	79	250
Viking Orb	639A92	19	45	720
Viking Orb	646A41	30	78	800
Viking Orb	687A18	21	54	700
Viking Orb	806A09	60	65	800
Viking Orb	372S56	42	48	233
Viking Orb	468S19	35	39	535

**References:**

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